TR 78043

ROYAL AIRCRAFT ESTABLISHMENT

*

Technical Report 78043

April 1978

THE EFFECT OF SALT AND SEA-WATER CONTAMINATION ON THE MECHANICAL PROPERTIES OF CORD AND WEBBING

by

J.E. Swallow

R.B. Gilmore

*

Procurement Executive, Ministry of Defence
Farnborough, Hants

LEVEL II

UDC 620.193.27 : 677.7 : 677.755

(19) BR-63952 (18) DRIC

ROYAL AIRCRAFT ESTABLISHMENT

(9) Technical Report 78043

Received for printing (11) 25 April 1978

(6) THE EFFECT OF SALT AND SEA-WATER CONTAMINATION ON THE MECHANICAL PROPERTIES OF CORD AND WEBBING

by

(10) J. E. Swallow
R. B. Gilmore

(14) RAE-TR-78043 (12) 33p.

SUMMARY

The effects of immersing a braided nylon cord, a flax webbing and a nylon webbing in salt solutions of various concentrations and in sea water have been investigated. Increases in mass per unit length were related to salt concentration and the calculated unoccupied space within the structures. No reduction in strength could be attributed to sodium chloride crystals. Reductions in the strength of nylon webbing occurred after immersion in sea water, consistent with the increased local relative humidity due to the deliquescing substances present in sea water. Washing did not remove all the contaminant from webbing.

The additional loss in strength due to immersion in sea water could be of concern in parachutes near the end of their Service life.

Departmental Reference: Mat 346

LIST OF CONTENTS

04

1 INTRODUCTION

The policy of parachuting into the sea is now established as a continuing requirement, both as a normal part of training and in specialist operation[1]. The parachutes are washed before returning to service[2], but there has been some evidence[1], particularly on reserve parachute lift webs, of strengths being below those expected.

It has been postulated that crystals from sea water remaining after washing, particularly in areas where drainage and concentration could occur, might have a cutting action during strength testing. It might also be that handling salt-contaminated materials could cause further breakage of filaments.

It has been noted[3] that yarns removed from tapes which had been exposed to an airstream containing a mixture of sand and salt could suffer strength reductions of over 20%. These losses were apparently mainly due to the pitting of filaments by the particles in the airstream, but it was thought that retained particles might have contributed.

Because of the importance of sea parachuting, and because there appeared to be a case for believing *a priori* that strength losses by this cutting mechanism were possible, it was considered necessary to establish by systematic investigation the effects of salt and of sea water contamination on parachute materials. This Report describes the work done on a nylon braided cord typical of rigging lines, and on flax and nylon webbing such as are used for harness and lift webs.

2 MATERIALS AND METHODS

2.1 Textiles

The following textiles were tested.

(a) Braided nylon cord CB203 of specification[4] DTD 5620

This cord had a minimum breaking strength of 1.8 kN, and a maximum mass per unit length of 5.5 g/m. It was of high tenacity nylon-66 and undyed.

(b) Flax harness webbing to specification[5] BS 2F111

This webbing had a minimum breaking strength of 13.5 kN, and a maximum width of 45 mm. It had been treated with mineral khaki and pentachlorophenol laurate.

(c) Nylon parachute harness webbing

043 This webbing was required[6] to have a minimum average breaking strength of 20.025 kN, a maximum mass per unit length of 76.9 g/m and a maximum width of 46 mm. It was of high tenacity nylon-66 and had been dyed olive drab.

2.2 Immersing liquids

The following liquids were used for immersion.

(a) Tap water

This was also used for washing. It was considered unnecessary to use chemically purer water since purity was not being investigated. A small increase in mass of a piece of textile due to solids remaining from immersion in water or from washing was therefore anticipated. Some increase in mass per unit length, particularly of the undyed cord, due to shrinkage, was also expected.

(b) 3% and 10% salt solutions

These were prepared by dissolving 30 or 100 g of technical sodium chloride in tap water in 1 litre volumetric flasks and making up to the mark. A 3% solution was selected since sea water contains this concentration of sodium chloride as its major constituent.

(c) Saturated salt solution

This was made by stirring sodium chloride into water until there was an obvious excess,to give about a 27% aqueous solution. The higher concentrations of salt were tested

(i) to attempt to exaggerate any effect of salt crystals experimentally, and

(ii) to simulate the effect of build up of salt by spray or by evaporation after drainage.

(d) Sea water from Studland Bay, Dorset.

2.3 Immersion, washing and drying

Immersions of the textiles, according to the experimental programme in section 4 and Table 1, took place in large basins. The time of immersion was generally 24 h, but in one set of tests was 7 days, at 20^{o}C. Washing, where specified in the programme, was performed by immersing the textiles in about 1 dm^3 of tap water in a large basin for 5 min at 20^{o}C. This time slightly exceeded the usual parachute washing time and the solid/liquid ratio was lower than it would be in practice; hence the laboratory washing could be expected to be more efficient than parachute washing, and any beneficial effects found from washing would be exaggerated. The specimens were allowed to dry horizontally (to minimise drainage to one end) across a sink and under a slight tension (to minimise catenary drain- 043
age to the centre) between clamps for at least 24 h. Pieces to be subsequently

tested for strength, extension and chloride content were handled as carefully as possible. In one series of tests, specimens were stored in a desiccator for 1 or 7 days.

2.4 Determination of responses

The following responses were determined.

(a) Mass per unit length

The textile was conditioned for at least 14 days at 20°C and 65% relative humidity. It was then loaded to 1% of the minimum permissible breaking load (18 N for the cord, 135 N for the flax webbing, and 200 N for the nylon webbing)[7], using flat jaws in a tensile testing machine. The textile was marked near the jaws and the length between the marks measured, ignoring stress relaxation. It was then released from tension, cut at the marks and weighed.

(b) Strength

This was determined on unhandled and handled specimens, using split-bollard grips for the cord, and flanged bollards[8] for the webbings.

(c) Extension at 0.9 kN

This was measured on the cord only, from the recorded load-extension curves, using wave-profile jaws. Higher loads were not used because specimen slippage tended to occur.

(d) Breaking extension

The breaking extension was determined on the webbings during the strength tests by making marks in the gauge length near each bollard before loading, and noting their change in positions with two travelling telescopes. The initial length of about 5 cm, when the webbings were under the load exerted by the clamp only, was measured by ruler. The extension at break was the difference between the difference in telescope readings at break and initially.

(e) Handling

This was assessed on the cord by submitting it to the core-looping test[7]. There is no such standard test for webbings; the procedure adopted for them was to insert one end into the upper jaw of a tensile-testing machine, and pull, twist and bend as much as possible during 1 min a region marked as that which would come under load in the subsequent strength test.

(f) Chloride content

This was determined on the cord only. The cord was trimmed and its length measured. It was weighed and placed in a Soxhlet extraction apparatus, which needed modification to prevent salt spray being carried up the side arm and salt solution being carried back up the siphon tube. The cord was extracted for at least 4 h with distilled water and chloride determined in the resultant solution by potentiometric titration with silver nitrate.

(g) Moisture regain of webbing

Specimens of length 10 cm were dried to constant mass (X) by heating in an oven at 105°C for 4 h, cooling in a desiccator, and weighing next day using a weighing bottle. The specimens were then soaked in the appropriate immersing liquid for 24 h at 20°C, dried horizontally on a sheet of plastic for 5 h, and then at 105°C for 4 h to constant mass (Y), determined as before. They were then exposed to an atmosphere at 20°C and 65% relative humidity for 3 days, to constant mass (Z). The regain was (Z-Y)/X, expressed as a percentage (*ie* the moisture content of the conditioned tested specimens/dry mass of the original nylon).

(h) Occupied and unoccupied volumes

The volume in cm^3 occupied by the fibre in 1 m length of textile was given by dividing the mass per unit length in g/m by the fibre density in g/cm^3.

The total volume in cm^3 occupied by 1 m of the textile was 100 × cross-sectional area of the textile in cm^2, derived from micrometer measurements.

The unoccupied volume in cm^3 of 1 m of textile was the total volume minus the occupied volume.

The volume of solution taken up by the textile was 100 × the average increase of mass per unit length in g/m for unit percentage increase in concentration.

3 EXPERIMENTAL DESIGNS

3.1 Cord

For mass per unit length, design A (Table 1) was adopted. The increase rather than the actual mass was taken as the response, since results before and after treatment were available on each piece. This amounted to a split-plot design, giving greater precision. However, the split-plot method could not be adopted for the other responses since the only results available were those after 043
treatment.

For strength, designs A and B (Table 1) were adopted (using 3% salt solution in the latter case), whilst breaking extension and salt content were analysed by design A.

The effects of time of immersion were investigated by design C (Table 1).

3.2 Flax webbing

The effects of conditions on the increase in mass per unit length and on the breaking extension were determined by design B using 3% salt solution, and on the strength using design B with either 3% salt solution or sea water.

3.3 Nylon webbing

The effects of conditions on the increase in mass per unit length, on the strength, and on the breaking extension were determined by design B using sea water.

4 EXPERIMENTAL PROGRAMME

4.1 Cord

For the cord, the stages in the experimental programme were as follows:

Two pieces (for replication) were cut in random order (to minimise length-related bias) from the reel for each of the responses. This required 80 cm for each strength test, 2 m (subsequently cut into two) for the handling tests, 25 cm for each extension test at half the minimum breaking strength, and 50 cm for each chloride test. For each immersion-time test, further 80 cm lengths were required and subsequently strength tested. The total length requirement was thus 53.6 m.

The mass per unit length of each 80 cm length (except those for the immersion-time tests) was determined. All the pieces were then immersed in the appropriate immersing liquid, and dried.

For those specimens which did not require washing, the appropriate pieces were tested for strength (immersion-time tests), mass per unit length, extension at 0.9 kN, or chloride, or were handled. Those tested for mass per unit length were then strength tested, whilst those which had been handled were cut in two and each piece strength tested.

Those specimens which required washing were washed, drained, rewashed and dried. The appropriate pieces were then tested as in the preceding paragraph.

043

4.2 Webbings

For the flax and nylon webbings, the stages in the experimental programme were as follows:

Two pieces were cut in random order (to minimise length-related bias) from the roll for each of the responses. This required 80 cm for each of the strength (including handling) tests and the total length requirement was thus 32 m.

The mass per unit length of each 80 cm length was determined. All the pieces were then immersed in the appropriate immersing liquid, and dried.

For those specimens which did not require washing, the appropriate pieces were tested for mass per unit length, or were handled and determinations made of strength and breaking extension.

Those specimens which required washing were washed, drained, rewashed and dried. The appropriate pieces were then tested as in the preceding paragraph.

5 RESULTS AND DISCUSSION

5.1 Cord

5.1.1 Mass per unit length

The mass per unit length results are given in Table 2, together with the means for each of the factor levels and analysis of variance of the increases.

All the factors were significant at well above the 99.9% level of probability. The increase in mass per unit length at zero concentration or after washing (somewhat less than 2%) was barely significant at the 99% level.

Washing reduced the mass increase due to salt to a value not significantly different from that due to immersion in tap water, irrespective of the salt concentration, indicating that the washing procedure effectively removed the salt.

5.1.2 Strength

The strength results are given in Table 3, together with the means for each of the levels of the factors, and analysis of variance.

None of the factors reached significance at a worthwhile probability level, and in no cases were the required differences achieved. Nevertheless, the overall mean strength did not quite meet the minimum required by the specification and some individual results were substantially below it. This may indicate that there was a reduction in strength due to immersion itself, which could have been caused by the higher regain which nylon possesses after conditioning from the wet state.

5.1.3 Strength after handling

The strengths after handling are also given in Table 3, together with the mean for each level of the factors, and analysis of variance. At the 99% probability level, the result depended on the concentration but not on the washing. Analysis of differences showed that it was only in the saturated solution that there was a lower strength on handling than in the other concentrations: the mean result was 8% lower than the specification minimum, and the values after immersion in 27% salt solution were 15% below it. It was not clear, however, why the washed specimens should also have had low strength after being in saturated salt solution, since they were washed before being handled.

The three-factor analysis of variance and the additional means generated are also given in Table 3. From this it is clear that the strength reduction on handling was very significant, but none of the interactions were of importance.

5.1.4 Extension

The extensions at 0.9 kN (half the specification minimum) are given in Table 3, together with the means for each of the factor levels, and analysis of variance.

None of the factors reached significance, and in no case was the required difference achieved.

5.1.5 Sodium chloride content

The sodium chloride contents are given in Table 3, together with the means for each of the factor levels, and analysis of variance.

Although the factors and the interaction were all significant, the variance ratios were lower than those for the increase in mass per unit length, and the differences required were achieved only in the case of the saturated salt solution; this was because the variability of the salt determinations was considerably greater than that of the increase in mass per unit length.

The correlation coefficients (r) between the salt content and increases in mass, the slopes (a) of the lines relating them, and the values of t for the difference of the slopes from unity were as follows:

	All data	Interaction	Effect of concentration
r	0.979	0.991	0.992
a	0.927	0.932	0.997
t	1.42	1.36	0.03
degrees of freedom	14	6	2

Thus, the correlation coefficients between them were high, and although the salt contents appeared on the average to be up to 7% lower than the increases in mass, these differences were not shown to be significant. In view of this, and the greater complexity and variability of the salt determinations, it would appear that the mass increase provides the better test in the present experiments, though this conclusion might be revised if mud or sand were present, or if substantial shrinkage took place.

5.1.6 Effect of immersion time on strength

The strengths following immersion for different times are given in Table 4, together with the means for each of the factor levels, and analysis of variance. The main purpose of this set was to test for possible chemical effects, particularly in sea water, which if present should be time-dependent, since they are slow reactions. It was first postulated that sea water possesses some oxidising action, but it was found[9] by measuring redox potential and by determining the reduction in oxidising power of potassium permanganate that sea water, in fact, had some reducing action. It might nevertheless be possible that dissolved air in the presence of water could have some wet oxidising action[10]. Hydrolytic attack would be unlikely, the pH being measured[9] as 7.3.

Neither time nor its interactions were found to be significant at the 99% level of probability. Condition was significant at this level, immersions in sea water and 3% salt solution giving lower strengths than the other conditions. Washing also increased the strength, probably due to washing the sea water specimens; the expected decrease on washing the desiccator specimens also occurred, though of insufficient magnitude to be significant.

5.2 Flax webbing

5.2.1 Mass per unit length

The mass per unit length results are given in Table 5, together with the means for each of the factor levels, and analysis of variance of the increases.

Very large variance ratios were obtained, particularly for the effects of concentration, washing, and their interaction, all being significant at well above the 99.9% probability level. In contrast to the nylon cord, however, the washed flax webbing retained a significant amount of salt, and the amount increased with the concentration. Handling appeared to increase the mass per unit length; the reason for this is not clear, but it may have been caused by shrinkage on handling rather than by an absolute increase in mass.

5.2.2 Strength and breaking extension

The strength and breaking extension results are given in Table 6, together with the means for each of the factor levels, and analysis of variance.

None of the factors or interactions reached worthwhile significance levels for any of the immersions, including those in sea water.

5.3 Nylon webbing

5.3.1 Mass per unit length

The mass per unit length results are given in Table 7, together with the means for each of the factor levels, and analysis of variance of the increases.

Very large variance ratios were obtained for the effects of concentration and washing, indicative of significance at well above the 99.9% probability level. The washed nylon may have retained some salt, but much less than the flax, and more similar to the cord. Handling the nylon webbing did not cause the increase in mass per unit length noted for the flax webbing.

5.3.2 Strength and breaking extension

The strength and breaking extension results are given in Table 8, together with the means for each of the factor levels, and analysis of variance. The effect of sea water immersion on strength was repeated, in order to confirm the findings.

Large variance ratios were obtained both in the original and the repeat analysis for the effects of concentration and washing on the strength. All of the immersions in salt solutions or in sea water produced lower strengths than the 0% immersion, and this effect was most marked in the unwashed sea water condition. Immersion in 10% salt solution produced strength losses in subsequent handling. Washing restored the strength of those specimens which had been immersed in sea water to values similar to those which had been immersed in salt solutions, but these still were lower than from immersion in 0% salt solution.

5.4 Additional responses

5.4.1 Effect of regain

The effect of regain (see section 2.4(g)) on the strength of the nylon webbing is given in Table 9. The regain from tap water and from 3% salt solution was close to that expected[11] from nylon at standard relative humidity (65%). The
043 regain from sea water was, however, considerably greater, probably because of deliquescing substances such as calcium and magnesium chlorides present in sea

water. This regain would imply a high local relative humidity in the nylon, which in turn would depress the strength[11]. Though it does not explain all the effects noted in sections 5.1-5.3 as probably occurring (such as the failure of washing to restore the strength of nylon webbing which had been immersed), the local relative humidity seems likely to have an influence on strength which is of the right order to account for observed losses. If the humidity mechanism were the only one operating, then the maximum strength loss which could occur would be[11] 15-20%, when the material was soaking wet, which could be of importance if the parachute were nearing the end of its permitted life. It may be noted on this explanation that the humidity effect should increase the strength of flax webbing, but the errors prevented any significant effect from emerging.

5.4.2 Occupied and unoccupied volumes

The occupied and unoccupied volumes (see section 2.4(h)) are given in Table 10. Although the nylon webbing had roughly similar mass per unit length and fibre volume to the flax webbing, it had a considerably higher total volume. Nevertheless the volume of solution absorbed was considerably less. It is possible that the dye molecules prevented the ingress of much of the salt. In the case of the cord, the ratio of solution absorbed to the unoccupied volume was not much greater than unity, the excess probably being due to additional material deposited on the surface. With the flax webbing the higher ratio may be accounted for by the extra surface area of a rectangular cross-sectional volume, as opposed to the circular cross section of the braid having minimum surface area per unit volume.

6 CONCLUSIONS

(1) The effects of immersion in sea water or salt solutions of various concentrations, and of subsequent washing and handling, on a nylon braided cord, a flax webbing and a nylon webbing, of types used in parachute components, have been investigated.

(2) There was a fairly linear increase in mass per unit length with salt concentration, though the volume of liquid taken up compared with that unoccupied by fibres in the structure depended on the textile.

(3) There was no evidence to support the hypothesis that salt crystals caused cutting damage to any of the materials during strength testing.

(4) Handling the nylon, particularly the cord, caused some strength loss, probably by distortion of the core relative to the sheath.

(5) The strength and breaking extension of the flax webbing were not significantly changed by any of the treatments. 043

(6) Nylon webbing (unwashed) suffered strength losses of about 6.5% after immersion in sea water.

(7) The higher moisture regain of nylon after immersion in sea water, due to deliquescing substances contained in it producing higher local relative humidity, could account for the strength loss of the magnitude found. Such losses may be dangerous in parachutes towards the end of their Service life (currently around ten years).

Acknowledgments

The authors thank Mr R.W. Fennell for sodium chloride determinations and Mr P.W. Reynolds, formerly of Textiles Section, Materials Department, for some of the other work on the braided cord.

Table 1

EXPERIMENTAL DESIGNS

Factor	Levels	No. of levels	No. of degrees of freedom	No. of results per level
DESIGN A				
Salt concentration, %	0, 3	4	3	4
Washing or handling	No, Yes	2	1	8
Interaction		8	3	2
Replication		2	8	1
Total		1	15	16
DESIGN B				
Salt concentration, %	0, 3 or sea, 10, 27	4	3	8
Washing	No, Yes	2	1	16
Handling	No, Yes	2	1	16
Salt concentration × washing		8	3	4
Salt concentration × handling		8	3	4
Washing × handling		4	1	8
Salt concentration × washing × handling		16	3	2
Replication		2	16	1
Total		1	31	32
DESIGN C				
Condition	Desiccator, tap water, sea water, 3% salt solution	4	3	8
Time, days	1, 7	2	1	16
Washing	No, Yes	2	1	16
Condition × time		8	3	4
Condition × washing		8	3	4
Time × washing		4	1	8
Condition × time × washing		16	3	2
Replication		2	16	1
Total		1	31	32

Table 2

MASS PER UNIT LENGTH OF CORD

(a) Results

Salt concentration, %	Washing	Replicate	Mass per unit length, g/m			
			Before immersion	After immersion	Increase	Mean increase (interaction)
0	No	1	5.38	5.49	0.12	0.06
0	No	2	5.38	5.40	0.02	
0	Yes	1	5.36	5.46	0.10	0.11
0	Yes	2	5.37	5.49	0.12	
3	No	1	5.39	5.59	0.19	0.22
3	No	2	5.38	5.62	0.24	
3	Yes	1	5.34	5.48	0.14	0.10
3	Yes	2	5.43	5.49	0.05	
10	No	1	5.40	5.96	0.56	0.61
10	No	2	5.30	5.96	0.66	
10	Yes	1	5.37	5.46	0.09	0.11
10	Yes	2	5.40	5.53	0.13	
27	No	1	5.35	6.98	1.63	1.62
27	No	2	5.32	6.94	1.61	
27	Yes	1	5.37	5.46	0.09	0.09
27	Yes	2	5.38	5.46	0.08	
		Mean	5.37	5.74	0.36	

(b) Means

Effect of concentration:

Concentration, %	0	3	10	27
Mean increase in mass per unit length	0.09	0.16	0.36	0.85

Effect of washing:

Washing	No	Yes
Mean increase in mass per unit length	0.63	0.10

(c) Analysis of variance

Factor	Variance ratio	Difference between means required at 99.9% probability
Concentration	267	0.15
Washing	574	0.11
Interaction	294	0.30
Error variance	0.00181	
Standard deviation	0.0425	
Coefficient of variation, %	11.7	

Table 3

STRENGTH, EXTENSION AND SALT CONTENT OF CORD

(a) Results

Salt concentration, %	Washing	Replicate	Strength without handling, kN	Strength after handling, kN	Extension at 0.9 kN, mm/m	Salt content, g/m	Interaction, mean			
							Strength without handling, kN	Strength after handling, kN	Extension at 0.9 kN, mm/m	Salt content, g/m
0	No	1	1.90	1.60	265	0.21	1.86	1.65	269	0.12
0	No	2	1.83	1.70	273	0.03				
0	Yes	1	1.80	1.74	251	0.01	1.77	1.72	275	0.01
0	Yes	2	1.73	1.70	299	0.02				
3	No	1	1.71	1.73	264	0.15	1.77	1.70	264	0.18
3	No	2	1.83	1.67	263	0.20				
3	Yes	1	1.78	1.62	276	0.04	1.76	1.66	270	0.03
3	Yes	2	1.73	1.70	263	0.03				
10	No	1	1.88	1.66	295	0.42	1.84	1.65	278	0.43
10	No	2	1.79	1.64	260	0.44				
10	Yes	1	1.85	1.75	243	0.05	1.77	1.74	261	0.04
10	Yes	2	1.68	1.74	279	0.04				
27	No	1	1.75	1.57	274	1.72	1.80	1.54	260	1.50
27	No	2	1.84	1.52	246	1.29				
27	Yes	1	1.86	1.51	278	0.14	1.74	1.52	276	0.12
27	Yes	2	1.61	1.52	275	0.09				

Table 3 (concluded)

(b) Means

Concentration, %	0	3	10	27	Effect of washing: No	Effect of washing: Yes	Overall mean
Strength without handling, kN	1.82	1.76	1.80	1.76	1.82	1.76	1.79
Strength after handling, kN	1.68	1.68	1.70	1.53	1.64	1.66	1.65
Overall strength, kN	1.75	1.72	1.75	1.65	1.73	1.71	1.72
Extension at 0.9 kN, mm/m	272	266	270	268	268	270	269
Salt content, g/m	0.07	0.10	0.24	0.81	0.56	0.05	0.30

(The first four value columns are under "Effect of concentration:".)

(c) Analysis of variance

Factor	Variance ratio: Strength without handling	Strength after handling	Overall strength	Extension at 0.9 kN	Salt content	Difference between means required at 99.9% probability: Strength without handling, kN	Strength after handling, kN	Overall strength, kN	Extension at 0.9 kN, mm/m	Salt content, g/m
Concentration	0.3	16.1	3.7	0.1	34.3	0.33	0.14	0.14	68	0.42
Washing	1.8	1.5	0.6	0.1	73.2	0.23	0.10	0.10	48	0.30
Handling			30.4					0.10		
Concentration × washing	0.1	3.0	0.2	0.6	25.8	0.65	0.28	0.28	136	0.84
Concentration × handling			1.8					0.28		
Washing × handling			2.9					0.20		
Concentration × washing × handling			1.0					0.57		
Error variance	0.00839	0.00155	0.00497	366	0.0139					
Standard deviation	0.0916	0.0394	0.0705	19.1	0.118					
Coefficient of variation, %	5.1	2.4	4.1	7.1	39.4					

Table 4

EFFECT OF IMMERSION TIME ON CORD STRENGTH

(a) Results

Condition	Washing	Time, days	Strength, kN Replicate 1	Strength, kN Replicate 2	Mean strength (3-factor interaction)
Desiccator	No	1	2.10	1.98	2.04
Desiccator	Yes	1	1.80	1.82	1.81
Desiccator	No	7	2.00	1.80	1.90
Desiccator	Yes	7	1.92	1.90	1.91
Tap water	No	1	1.81	1.92	1.86
Tap water	Yes	1	2.20	2.00	2.10
Tap water	No	7	1.79	1.77	1.78
Tap water	Yes	7	1.80	1.78	1.79
Sea water	No	1	1.60	1.64	1.62
Sea water	Yes	1	1.82	2.02	1.92
Sea water	No	7	1.63	1.50	1.56
Sea water	Yes	7	1.80	1.84	1.82
3% salt	No	1	1.68	1.65	1.66
3% salt	Yes	1	1.88	1.84	1.86
3% salt	No	7	1.70	1.60	1.65
3% salt	Yes	7	1.85	1.75	1.80

(b) Means

Effect of condition:

Condition	Desiccator	Tap water	Sea water	3% salt solution
Strength, kN	1.92	1.88	1.73	1.74

Effect of washing:

Washing	No	Yes
Strength, kN	1.76	1.88

Effect of time:

Time, days	1	7
Strength, kN	1.86	1.78

Effect of condition × washing and condition × time:

Condition		Desiccator	Tap water	Sea water	3% salt solution
Washing	No	1.97	1.82	1.59	1.66
	Yes	1.86	1.94	1.87	1.83
Time, days	1	1.92	1.98	1.77	1.76
	7	1.90	1.78	1.69	1.72

Effect of washing × time:

		Washing No	Washing Yes
Time, days	1	1.80	1.92
	7	1.72	1.83

Overall mean: 1.82 kN

Table 4 (concluded)

(c) Analysis of variance

Factor	Variance ratio	Difference between means required at 99.9% probability
Condition	12.0	0.16
Washing	18.0	0.11
Time	9.3	0.11
Condition × washing	9.0	0.31
Condition × time	2.2	0.31
Time × washing	0.1	0.22
Condition × washing × time	3.1	0.62
Error variance	0.00596	
Standard deviation	0.077	
Coefficient of variation, %	4.2	

Table 5

MASS PER UNIT LENGTH OF FLAX WEBBING

(a) Results

Salt concentration, %	Washing	Handling	Replicate	Mass per unit length, g/m: Before immersion	After immersion	Increase	Mean of replicates (3-factor interaction)
0	No	No	1	72.7	73.8	1.1	1.1
0	No	No	2	73.0	74.1	1.1	
0	No	Yes	1	73.1	74.7	1.6	1.5
0	No	Yes	2	73.3	74.7	1.4	
0	Yes	No	1	72.7	74.2	1.5	1.2
0	Yes	No	2	71.8	72.6	0.8	
0	Yes	Yes	1	74.0	75.7	1.7	1.5
0	Yes	Yes	2	72.6	73.9	1.3	
3	No	No	1	72.5	76.5	4.0	3.6
3	No	No	2	72.8	76.1	3.3	
3	No	Yes	1	72.9	76.3	3.4	3.9
3	No	Yes	2	72.8	77.2	4.4	
3	Yes	No	1	72.5	74.6	2.1	2.4
3	Yes	No	2	72.2	74.8	2.6	
3	Yes	Yes	1	72.9	75.7	2.8	2.8
3	Yes	Yes	2	73.3	76.0	2.7	
10	No	No	1	72.0	81.4	9.4	9.6
10	No	No	2	72.7	82.4	9.7	
10	No	Yes	1	72.8	83.2	10.4	10.2
10	No	Yes	2	72.8	82.9	10.1	
10	Yes	No	1	72.4	77.9	5.5	5.6
10	Yes	No	2	72.7	78.3	5.6	
10	Yes	Yes	1	72.5	79.0	6.5	6.1
10	Yes	Yes	2	73.9	79.6	5.7	
27	No	No	1	72.4	89.4	17.0	16.8
27	No	No	2	72.7	89.2	16.5	
27	No	Yes	1	72.2	92.7	20.5	20.2
27	No	Yes	2	72.5	92.4	19.9	
27	Yes	No	1	73.2	81.4	8.2	8.5
27	Yes	No	2	73.2	82.0	8.8	
27	Yes	Yes	1	73.2	81.2	8.0	9.0
27	Yes	Yes	2	72.1	82.1	10.0	
			Mean	72.8	79.3	6.5	

Table 5 (concluded)

(b) Means

Effect of concentration:

Concentration, %	0	3	10	27
Mean increase in mass per unit length, g/m	1.3	3.2	7.9	13.6

Effect of washing:

Washing	No	Yes
Mean increase in mass per unit length, g/m	8.4	4.6

Effect of handling:

Handling	No	Yes
Mean increase in mass per unit length, g/m	6.1	6.9

Effect of concentration × washing and concentration × handling:

Concentration		0	3	10	27
Washing	No	1.3	3.8	9.9	18.5
	Yes	1.3	2.6	5.8	8.8
Handling	No	1.1	3.0	7.6	12.6
	Yes	1.5	3.3	8.2	14.6

Effect of washing × handling:

		Handling No	Handling Yes
Washing	No	7.8	4.4
	Yes	9.0	4.8

(c) Analysis of variance

Factor	Variance ratio	Difference between means required at 99.9% probability
Concentration	937.1	1.0
Washing	436.9	0.7
Handling	21.1	0.7
Concentration × washing	146.1	2.0
Concentration × handling	4.7	2.0
Washing × handling	9.6	1.4
Concentration × washing × handling	2.4	4.1
Error variance	0.258	
Standard deviation	0.507	
Coefficient of variation, %	7.8	

043

Table 6

STRENGTH AND BREAKING EXTENSION OF FLAX WEBBING

(a) Results

Salt concentration, %	Washing	Handling	Replicate	Strength, kN	Mean of replicates (interaction)	Breaking extension, mm/m	Mean of replicates (interaction)
0	No	No	1	14.0	14.9	64	52
0	No	No	2	15.8		40	
0	No	Yes	1	14.3	14.4	36	74
0	No	Yes	2	14.6		112	
0	Yes	No	1	13.4	12.7	56	63
0	Yes	No	2	12.0		70	
0	Yes	Yes	1	15.0	15.1	70	80
0	Yes	Yes	2	15.2		90	
3	No	No	1	14.8	14.8	78	71
3	No	No	2	14.8		64	
3	No	Yes	1	14.8	14.8	90	93
3	No	Yes	2	14.8		96	
3	Yes	No	1	15.5	15.4	80	81
3	Yes	No	2	15.3		82	
3	Yes	Yes	1	14.8	15.1	64	58
3	Yes	Yes	2	15.4		52	
10	No	No	1	15.4	14.9	96	97
10	No	No	2	14.4		98	
10	No	Yes	1	13.5	13.8	92	97
10	No	Yes	2	14.2		102	
10	Yes	No	1	15.3	15.0	72	97
10	Yes	No	2	14.6		122	
10	Yes	Yes	1	14.8	14.6	68	70
10	Yes	Yes	2	14.3		72	
27	No	No	1	14.1	14.0	130	120
27	No	No	2	14.0		110	
27	No	Yes	1	13.8	13.9	72	68
27	No	Yes	2	14.0		64	
27	Yes	No	1	15.6	15.0	94	92
27	Yes	No	2	14.4		90	
27	Yes	Yes	1	14.4	15.0	98	92
27	Yes	Yes	2	15.6		86	
			Mean	14.6		82	

Table 6 (continued)

(b) Means

Effect of concentration:

Concentration	0	3	10	27
Strength, kN	14.3	15.0	14.6	14.5
Breaking extension, mm/m	67	76	90	93

Effect of washing:

Washing	No	Yes
Strength, kN	14.5	14.7
Breaking extension, mm/m	84	79

Effect of handling:

Handling	No	Yes
Strength, kN	14.6	14.6
Breaking extension, mm/m	84	79

Effect of concentration × washing:

Concentration		Strength, kN 0	3	10	27	Breaking extension, mm/m 0	3	10	27
Washing	No	14.7	14.8	14.4	14.0	63	82	97	94
	Yes	13.9	15.2	14.8	15.0	72	70	84	92

Effect of concentration × handling:

Concentration		Strength, kN 0	3	10	27	Breaking extension, mm/m 0	3	10	27
Handling	No	13.8	15.1	14.9	14.5	58	76	97	94
	Yes	14.8	15.0	14.2	14.4	77	76	84	92

Effect of washing × handling:

Washing		Strength, kN No	Yes	Breaking extension, mm/m No	Yes
Handling	No	14.7	14.5	85	83
	Yes	14.2	14.9	83	75

Table 6 (concluded)

(c) Analysis of variance

Factor	Variance ratio		Difference between means required at 99% probability	
	Strength	Breaking extension	Strength	Breaking extension
Concentration	2.3	3.6	0.8	26
Washing	1.7	0.6	0.6	19
Handling	0.0	0.6	0.6	19
Concentration × washing	3.3	0.6	1.7	53
Concentration × handling	2.9	2.3	1.7	53
Washing × handling	4.1	0.2	1.2	38
Concentration × washing × handling	2.9	2.7	3.4	106
Error variance	0.340	330		
Standard deviation	0.583	18.2		
Coefficient of variation, %	4.0	22.2		

(d) Strength results with sea water instead of 3% salt solution

Washing	Handling	Replicate	Strength, kN
No	No	1	13.2
No	No	2	13.2
No	Yes	1	14.8
No	Yes	2	16.2
Yes	No	1	16.0
Yes	No	2	15.6
Yes	Yes	1	14.3
Yes	Yes	2	16.4

(e) Analysis of variance using (d)

Factor	Variance ratio
Concentration	1.1
Washing	3.4
Handling	1.2
Concentration × washing	2.9
Concentration × handling	2.6
Washing × handling	0.2
Concentration × washing × handling	5.2
Error variance	0.531
Standard deviation	0.728
Coefficient of variation, %	5.0

Table 7

MASS PER UNIT LENGTH OF NYLON WEBBING

(a) Results

Salt concen-tration, %	Wash-ing	Hand-ling	Repli-cate	Mass per unit length, g/m			
				Before immersion	After immersion	Increase	Mean of replicates (3-factor interaction)
0	No	No	1	64.6	65.0	0.4	0.3
0	No	No	2	64.8	65.0	0.2	
0	No	Yes	1	64.1	64.5	0.3	0.4
0	No	Yes	2	64.1	64.6	0.5	
0	Yes	No	1	64.5	65.0	0.5	0.4
0	Yes	No	2	64.0	64.6	0.4	
0	Yes	Yes	1	64.1	64.4	0.3	0.4
0	Yes	Yes	2	64.6	65.1	0.5	
Sea	No	No	1	64.6	67.8	3.2	3.2
Sea	No	No	2	64.6	67.8	3.2	
Sea	No	Yes	1	64.7	66.4	1.7	2.0
Sea	No	Yes	2	64.0	66.2	2.2	
Sea	Yes	No	1	64.0	65.0	1.0	0.9
Sea	Yes	No	2	64.4	65.2	0.8	
Sea	Yes	Yes	1	64.1	65.3	1.2	1.0
Sea	Yes	Yes	2	64.4	65.3	0.9	
10	No	No	1	64.7	69.6	4.9	4.8
10	No	No	2	64.4	69.0	4.6	
10	No	Yes	1	64.6	69.4	4.8	4.7
10	No	Yes	2	64.6	69.2	4.6	
10	Yes	No	1	64.9	65.6	0.7	0.8
10	Yes	No	2	64.8	65.8	1.0	
10	Yes	Yes	1	64.7	65.7	1.0	1.0
10	Yes	Yes	2	64.1	65.1	1.0	
27	No	No	1	64.3	75.5	11.2	11.3
27	No	No	2	64.5	75.9	11.4	
27	No	Yes	1	64.0	74.4	10.4	10.0
27	No	Yes	2	64.6	74.1	9.5	
27	Yes	No	1	64.5	65.0	0.5	0.8
27	Yes	No	2	64.5	65.5	1.0	
27	Yes	Yes	1	64.3	65.4	1.1	1.0
27	Yes	Yes	2	64.6	65.6	1.0	
			Mean	64.4	67.1	2.7	

Table 7 (concluded)

(b) Means

Effect of concentration, %:

Concentration, %	0	Sea water	10	27
Mean increase in mass per unit length, g/m	0.4	1.8	2.8	5.8

Effect of washing:

Washing	No	Yes
Mean increase in mass per unit length, g/m	4.6	0.8

Effect of handling:

Handling	No	Yes
Mean increase in mass per unit length, g/m	2.8	2.6

Effect of concentration × washing and concentration × handling:

Concentration, %		0	Sea water	10	27
Washing	No	0.4	2.6	4.7	10.6
	Yes	0.4	1.0	0.9	0.9
Handling	No	0.4	2.0	2.8	6.0
	Yes	0.4	1.5	2.8	5.5

Effect of washing × handling:

		Handling No	Handling Yes
Washing	No	4.9	4.3
	Yes	0.7	0.9

(c) Analysis of variance

Factor	Variance ratio	Difference between means required at 99.9% probability
Concentration	732.6	0.5
Washing	2008.9	0.4
Handling	8.4	0.4
Concentration × washing	645.5	1.0
Concentration × handling	4.1	1.0
Washing × handling	20.6	0.7
Concentration × washing × handling	7.2	2.0
Error variance	0.0566	
Standard deviation	0.238	
Coefficient of variation, %	8.8	

04

Table 8

STRENGTH AND BREAKING EXTENSION OF NYLON WEBBING

(a) Results

Salt concen-tration, %	Wash-ing	Hand-ling	Repli-cate	Strength, kN	Mean of replicates (3-factor interaction)	Breaking extension, mm/m	Mean of replicates (3-factor interaction)
0	No	No	1	18.5	18.6	338	361
0	No	No	2	18.7		384	
0	No	Yes	1	19.0	18.8	320	320
0	No	Yes	2	18.5		320	
0	Yes	No	1	18.5	18.8	314	312
0	Yes	No	2	19.0		310	
0	Yes	Yes	1	19.0	19.0	350	352
0	Yes	Yes	2	19.0		354	
Sea	No	No	1	17.1	17.0	342	324
Sea	No	No	2	17.0		306	
Sea	No	Yes	1	17.2	17.4	320	332
Sea	No	Yes	2	17.5		344	
Sea	Yes	No	1	18.0	18.0	356	328
Sea	Yes	No	2	18.0		302	
Sea	Yes	Yes	1	18.0	18.2	336	326
Sea	Yes	Yes	2	18.4		316	
10	No	No	1	18.4	18.4	322	320
10	No	No	2	18.4		318	
10	No	Yes	1	17.2	17.4	310	303
10	No	Yes	2	17.5		296	
10	Yes	No	1	18.0	18.0	316	328
10	Yes	No	2	18.0		340	
10	Yes	Yes	1	17.5	17.5	336	327
10	Yes	Yes	2	17.5		318	
27	No	No	1	18.0	18.0	296	284
27	No	No	2	18.0		272	
27	No	Yes	1	18.0	18.0	330	323
27	No	Yes	2	18.0		316	
27	Yes	No	1	18.4	18.4	334	306
27	Yes	No	2	18.4		278	
27	Yes	Yes	1	18.4	18.4	302	296
27	Yes	Yes	2	18.4		290	
			Mean	18.1		318	

Table 8 (continued)

(b) Means

Effect of concentration:

Concentration, %	0	Sea water	10	27
Strength, kN	18.8	17.6	17.8	18.2
Breaking extension, mm/m	336	328	320	302

Effect of washing:

Washing	No	Yes
Strength, kN	17.9	18.3
Breaking extension, mm/m	321	322

Effect of handling:

Handling	No	Yes
Strength, kN	18.2	18.0
Breaking extension, mm/m	320	322

Effect of concentration × washing and concentration × handling on strength:

Effect of concentration × washing and concentration × handling on breaking extension:

Concentration, %		0	Sea water	10	27
Washing	No	18.7	17.0	17.9	18.0
	Yes	18.9	18.1	17.8	18.4
Handling	No	18.7	17.5	18.2	18.2
	Yes	18.9	17.6	17.4	18.2
Washing	No	340	328	312	304
	Yes	332	328	328	301
Handling	No	336	326	324	295
	Yes	332	329	315	310

Effect of washing × handling on strength:

Effect of washing × handling on breaking extension:

		Washing No	Washing Yes
Handling	No	18.0	18.3
	Yes	17.8	18.3
Handling	No	322	319
	Yes	320	325

Table 8 (concluded)

(c) Analysis of variance

Factor	Variance ratio		Difference between means required for	
	Strength	Breaking extension	Strength at 99.9% probability	Breaking extension at 99% probability
Concentration	89.2	4.3	0.3	29
Washing	48.1	0.0	0.2	20
Handling	5.0	0.1	0.2	20
Concentration × washing	20.6	0.6	0.6	58
Concentration × handling	15.6	0.5	0.6	58
Washing × handling	4.1	0.4	0.4	41
Concentration × washing × handling	1.2	3.8	1.3	115
Error variance	0.025	391		
Standard deviation	0.158	19.8		
Coefficient of variation, %	0.9	6.2		

(d) Strength results in second sea water immersion

Washing	Handling	Replicate	Strength, kN
No	No	1	17.8
No	No	2	17.2
No	Yes	1	17.5
No	Yes	2	17.7
Yes	No	1	18.5
Yes	No	2	18.5
Yes	Yes	1	18.5
Yes	Yes	2	18.5
		Mean	18.2

(e) Analysis of variance using (d)

Factor	Variance ratio
Concentration	42.4
Washing	31.5
Handling	4.3
Concentration × washing	12.6
Concentration × handling	11.9
Washing × handling	1.2
Concentration × washing × handling	1.3
Error variance	0.0320
Standard deviation	0.179
Coefficient of variation, %	1.0

Table 9

EFFECT OF REGAIN ON STRENGTH OF NYLON WEBBING

Immersing liquid	Mass increase[a] after immersion, on oven dry basis, % Y	Increase in mass per unit length[a] (derived from Table 7), on conditioned basis, % Z-Y	Moisture regain[a], % (Z-Y)/X	Equivalent local relative humidity[11], %	Expected strength at equivalent local RH[b], kN	Actual strength, kN
Tap water	0.1	0.5	4.5	72	18.8	18.8
3% salt solution	2.1	-	4.6	73	18.7	-
Sea water	2.3	5.0	7.3	95	16.9	17.6

a see section 2.4(g)
b assuming 15% strength loss at linear rate between 72% RH and 95% RH

Table 10

OCCUPIED AND UNOCCUPIED VOLUMES (see section 2.4(h))

Textile	Mass per unit length, g/m	Fibre volume, cm^3	Total volume, cm^3	Unoccupied volume, cm^3	Volume of solution absorbed, cm^3	Ratio of volume of solution absorbed to unoccupied volume
Cord	5.4	4.7	9.6	4.9	5.5	1.1
Flax webbing	72.8	47.3	86.0	38.7	63.0	1.6
Nylon webbing	64.4	56.5	126.0	69.5	38.3	0.6

0

REFERENCES

No	Author	Title, etc
1	E.A. Brittain	Private communication (1976)
2	-	General and technical information on the 22 ft steerable static-line operated parachute. AP 108C-0219-1 Chapter 30, p 15 paras 1-6 (1971)
3	J.E. Swallow	Unpublished work (1968)
4	Procurement Executive, Ministry of Defence	Aircraft material specification: braided nylon cord. DTD 5620 (1976)
5	British Standards Institution	Flax harness webbing. BS 2F111 (1973)
6	-	Unpublished specification (1976)
7	British Standards Institution	Inspection and testing of textiles BS 3F100 (1975)
8	Bridget Stagg	Translation of textile yarn properties in cordage. RAE Technical Report 74085 (1974)
9	A.J. Christopher	Private communication (1977)
10	E. Mikolajeuski J.E. Swallow M. Webb	Wet oxidation of undrawn nylon-66 and model amides. RAE Report Chem. 531 (1962)
11	W.E. Morton J.W.S. Hearle	Physical properties of textile fibres. Manchester & London, The Textile Institute & Butterworths, (1962)

REPORT DOCUMENTATION PAGE

Overall security classification of this page

UNCLASSIFIED

As far as possible this page should contain only unclassified information. If it is necessary to enter classified information, the box above must be marked to indicate the classification, e.g. Restricted, Confidential or Secret.

1. DRIC Reference (to be added by DRIC)	2. Originator's Reference	3. Agency Reference	4. Report Security Classification/Marking
	RAE TR 78043	N/A	Unclassified

5. DRIC Code for Originator	6. Originator (Corporate Author) Name and Location
850100	Royal Aircraft Establishment, Farnborough, Hants, UK

5a. Sponsoring Agency's Code	6a. Sponsoring Agency (Contract Authority) Name and Location
N/A	N/A

7. Title The effect of salt and sea-water contamination on the mechanical properties of cord and webbing

7a. (For Translations) Title in Foreign Language

7b. (For Conference Papers) Title, Place and Date of Conference

8. Author 1. Surname, Initials	9a. Author 2	9b. Authors 3, 4	10. Date	Pages	Refs.
Swallow, J.E.	Gilmore, R.B.		April 1978	31	11

11. Contract Number	12. Period	13. Project	14. Other Reference Nos.
N/A	N/A		Mat 346

15. Distribution statement

(a) Controlled by – [redacted]

(b) Special limitations (if any) –

16. Descriptors (Keywords) (Descriptors marked * are selected from TEST)

Nylon. Flax. Parachutes. Webbing. Braided cord. Strength. Mass per unit length. Sodium chloride (salt). Sea water. Washing. Handling.

17. Abstract

The effects of immersing a braided nylon cord, a flax webbing and a nylon webbing in salt solutions of various concentrations and in sea water have been investigated. Increases in mass per unit length were related to salt concentration and the calculated unoccupied space within the structures. No reduction in strength could be attributed to sodium chloride crystals. Reductions in the strength of nylon webbing occurred after immersion in sea water, consistent with the increased local relative humidity due to the deliquescing substances present in sea water. Washing did not remove all the contaminant from webbing.

The additional loss in strength due to immersion in sea water could be of concern in parachutes near the end of their Service life.

RAE Form A143